Traditional Scenarios

Traditional scenarios are created using the scenario-axis technique pioneered by Schwartz (1996). Traditional scenarios are typically constructed by considering the combinations of extreme values of two or three key uncertain factors. The art of scenario construction lies in identifying the key uncertain factors and assuring a compelling and plausible pathway (typically described in a narrative) for such an outcome to occur. The likelihood of such scenarios of occurring is typically not considered in the analysis.

Using the scenarios-axes technique, RAND specified two critical uncertainties about the performance of IEUA's water management – (1) the impact of climate change on hydrology in the IEUA region and source region of imports and (2) the ability of IEUA to meet its management goals. For each uncertainty, RAND specified two levels, producing four discrete scenarios.

To define the uncertainty in future climate RAND selected two climate time series with temperature and precipitation trends at opposing ends of the continuum suggested by ensembles of global circulation models. A slightly warmer and wetter scenario and hotter and drier scenarios were chosen (Table 8). To define the uncertainty about the ability of IEUA to meet its goals we chose two levels of achievement for direct use of recycled water by urban users and the annual Chino Basin artificial replenishment rate, drawn from surveys administered to the workshop participants in the first workshop (Table 9).

Table 1: Parameters associated with two climate scenarios.

	Slightly warmer	Hotter and drier
Temperature change (2005-2030)	+0.7 deg C	+1.6 deg C
Precipitation change (2005-2030)	+3%	-10%

Table 2: Parameters associated with the two levels of UWMP goal achievement.

	Meet Goals	Miss Goals
Direct Use of Recycled Water	39 taf (2010) ; 69 taf (2025)	30 taf (2010) ; 50 taf (2025)
Chino Basin Replenishment	90 taf (2010) ; 107 taf (2025)	90 taf (2010) ; 90 taf (2025)

We evaluated the performance of four different management strategies in the four scenarios – the 2005 UWMP and three variations that included additional management actions. The additional management actions were identified from user surveys administered during the first workshop. For one action, we adjusted the IEUA Plan to increase efficiency improvement to 15% in 2015 and 20% in 2020. For the other, we increased the allowable amount of recycled water for Chino Basin replenishment by 20% (over the amount projected by the 2005 UWMP). This action only affects years in which imported supply for replenishment is limited. With a higher allowable recycled content in replenishment, this leads to greater replenishment during years in which imports are low. Table 10 lists the scenarios and strategies evaluated for the Scenario analysis.

Table 3: Variable climate scenario analysis – scenarios and management strategies

Scenario		Management Strategy	
S1	Slightly warmer, meet goals	A	2005 UWMP
S2	Slightly warmer, miss goals	B	2005 UWMP + efficiency
S3	Hotter and drier, meet goals	C	2005 UWMP + replenishment
S4	Hotter and drier, miss goals	D	2005 UWMP + efficiency and replenishment

Figure 1 to **Figure 4** show the mix of supply delivered to meet demand (colored/grey areas), any available surplus (white area), and any unmet demand (black area) under the 2005 UWMP for the four scenarios. Under the slightly warmer climate scenario, even when goals are missed by the amounts specified in

Table 2 (Scenario 2) there are no projected shortages. Under the Hotter and Drier climate scenario, however, shortages are projected, particularly when the recycling and replenishment goals are not met (Scenario 4).

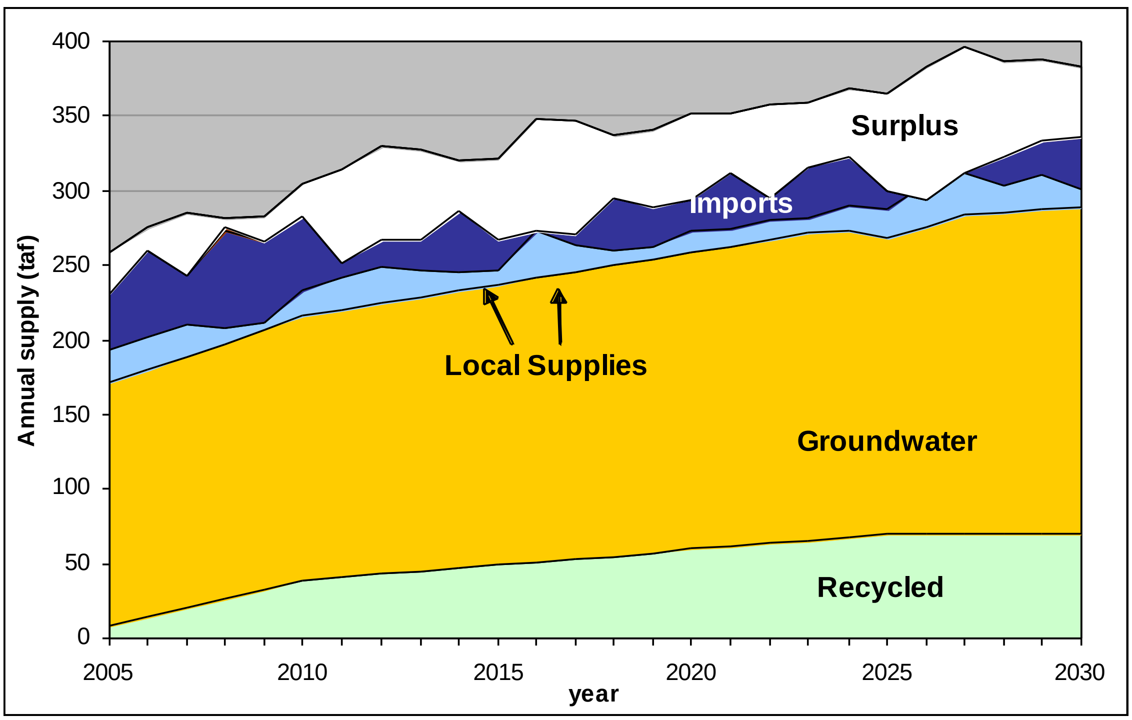

Figure 1: Delivered supply, surplus, and shortages for the Slightly Warmer, Meet All Goals scenario under the 2005 UWMP (S1-A).

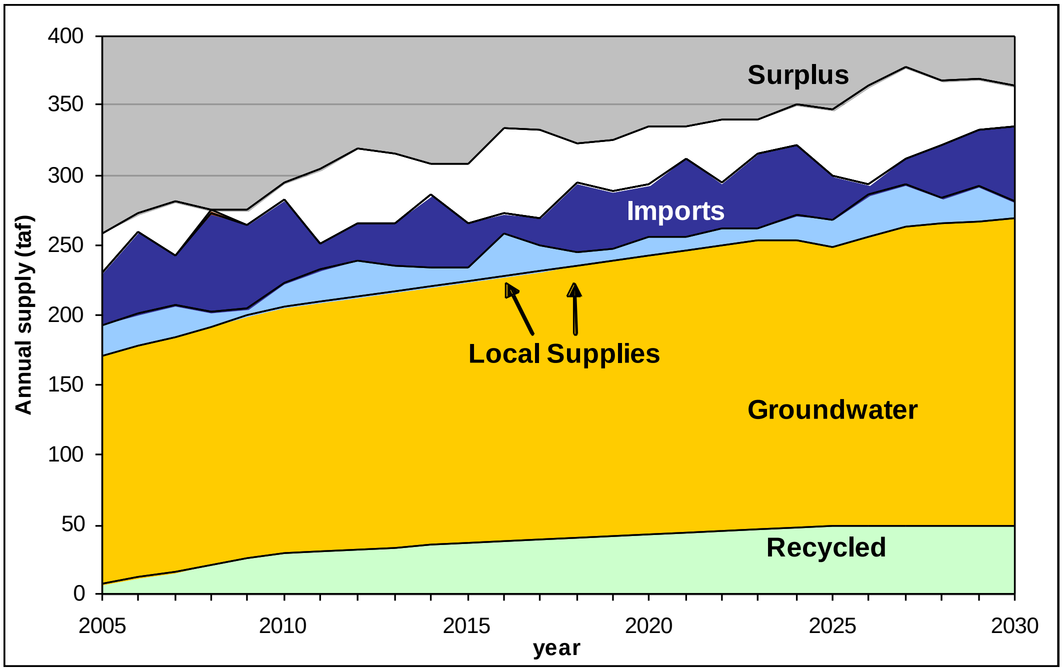

Figure 2: Delivered supply, surplus, and shortages for the Slightly Warmer, Miss Goals scenario under the 2005 UWMP (S2-A).

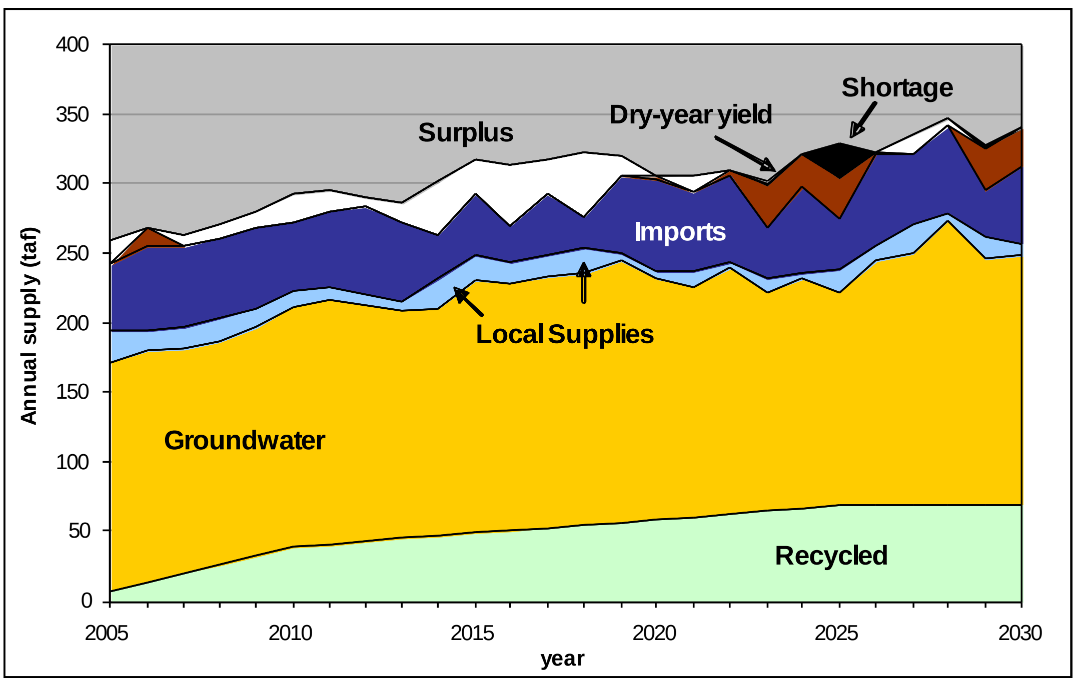

Figure 3: Delivered supply, surplus, and shortages for the Hotter and Drier, Meet All Goals scenario and the 2005 UWMP (S3-A).

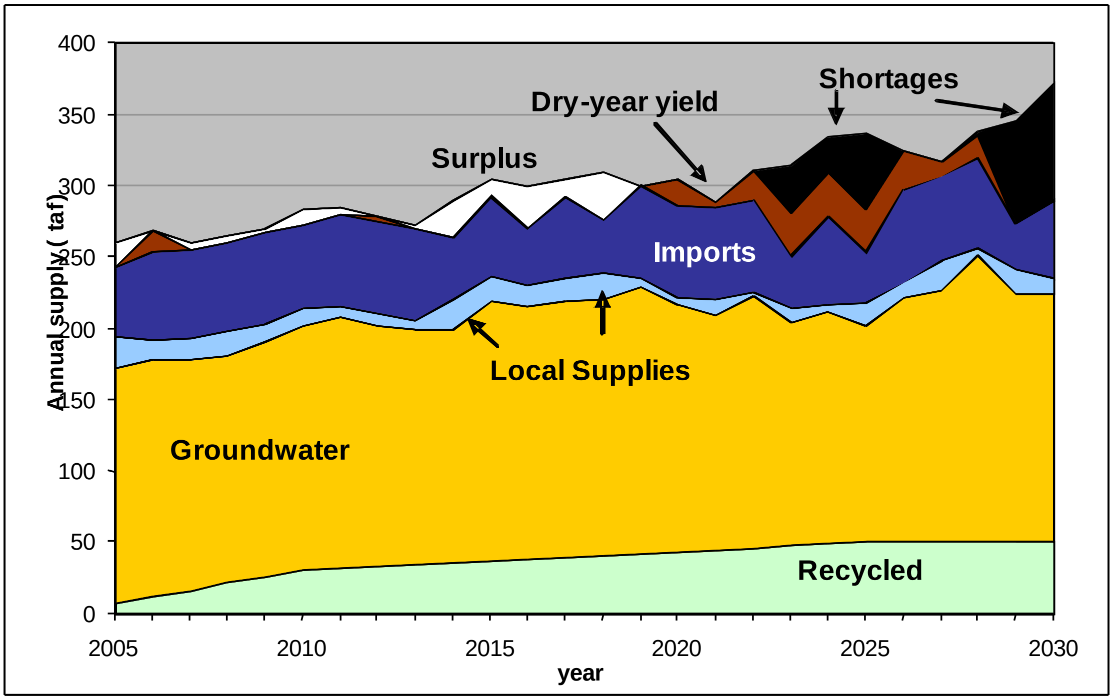

Figure 4: Delivered supply, surplus, and shortages for the Hotter and Drier, Miss Goals scenario and the 2005 UWMP (S4-A).

Table 4 provides a comparison of performance of the four strategies under the four scenarios as measured by percentage of years in which shortages exist between 2005 and 2030. In this and following stoplight charts, colors are used to signify relative desirability of the outcomes. Consistent with **Figure 1** and **Figure 2** (above) no shortages are projected for Plan A (2005 UWMP) under the two Slightly Warmer scenarios (S1 and S2). As Plans B – D either reduce demand or increase supply (via increased Chino Basin groundwater replenishment) no shortages are projected for them under scenarios S1 and S2. Under the Hotter and Drier, Meet Goals scenarios (S3), Plans A and C lead to shortages 19% and 12% of the years, whereas Plans B and D are largely shortage free. Finally, under the Hotter and Drier, Miss Goals scenario, all Plans lead to shortages, although Plan D leads to the lowest frequency of shortages (15%). Using this metric, Plan D is the best or equally as good as all other plans under all scenarios.

Table 4: Percent of years with shortages for four management plans under four scenarios.
Cells with shortages less than 10% are shaded green, between 10% and 20% are shaded yellow, and greater than 20% are shaded red.

Management Strategy	Scenario			
	S1: Slightly Warmer, Meet Goals	**S2: Slightly Warmer, Miss Goals**	**S3: Hotter and Drier, Meet Goals**	**S4: Hotter and Drier, Miss Goals**
Plan A (2005 UWMP)	**0%**	**0%**	**19%**	**42%**
Plan B (+ efficiency)	**0%**	**0%**	**4%**	**27%**
Plan C (+ recycled	**0%**	**0%**	**12%**	**42%**

replenishment) **Plan D** (+ efficiency & replenishment	**0%**	**0%**	**0%**	**15%**

Table 5 shows the performance of the four plans under the four scenarios as measured by the average surplus between 2005 and 2030. Using this metric, we see that Plans B, C, and D lead to very large and potentially undesirable surpluses (greater than 40 taf) under the Slightly Warmer, Meet Goals scenario.1 Using this metric, Plan D is the best under S3 and S4, about equal to all the plans under S2, and the worst plan under S1.

Table 5: Average surplus (2005-2030) for four management plans under four scenarios. Cells with surpluses between 20 and 40 taf are shaded green, between 10 and 20 taf and between 40 and 60 taf are shaded yellow, and less than 10 taf and greater than 60 taf are shaded red.

Management Strategy	**Scenario**			
	S1: Slightly Warmer, Meet Goals	**S2: Slightly Warmer, Miss Goals**	**S3: Hotter and Drier, Meet Goals**	**S4: Hotter and Drier, Miss Goals**
Plan A (2005 UWMP)	**39 taf**	**26 taf**	**11 taf**	**8 taf**
Plan B (+ efficiency)	**51 taf**	**35 taf**	**17 taf**	**9 taf**
Plan C (+ recycled replenishment)	**43 taf**	**27 taf**	**14 taf**	**8 taf**
Plan D (+ efficiency & replenishment	**52 taf**	**36 taf**	**19 taf**	**11 taf**

Probability-weighted Scenarios

Our second approach to evaluating the performance of water management actions under uncertainty was to generate a large ensemble of plausible scenarios and weight them by best-available probabilities.2 As in the scenario approach, we considered uncertainty about the effect of climate change on Chino Basin weather and the ability of IEUA agencies to meet their recycling and Chino Basin replenishment goals.

We considered 90 different weather sequences, ten for each decile of the CDF developed by NCAR. We weighted each of the climate sequences according to the associated probability density functions (PDF) for temperature and precipitation. **Figure 5** shows the PDFs for winter precipitation and summer temperature. The numbers indicate the decile number – a lower decile signifies a warmer and drier sequence. As an example, a simulation based upon a weather sequence selected from the 2nd precipitation and temperature decile would be weighted about twice as much as sequences selected from the 1st decile (relative weights of 0.1 versus 0.05).

[1] Outcomes with large surpluses may be considered undesirable as they indicate unnecessary investment in capacity expansion.

[2] Weighting a large set of simulations, each evaluated using a different value for uncertain parameters is one approach to computing a “probabilistic forecast”.

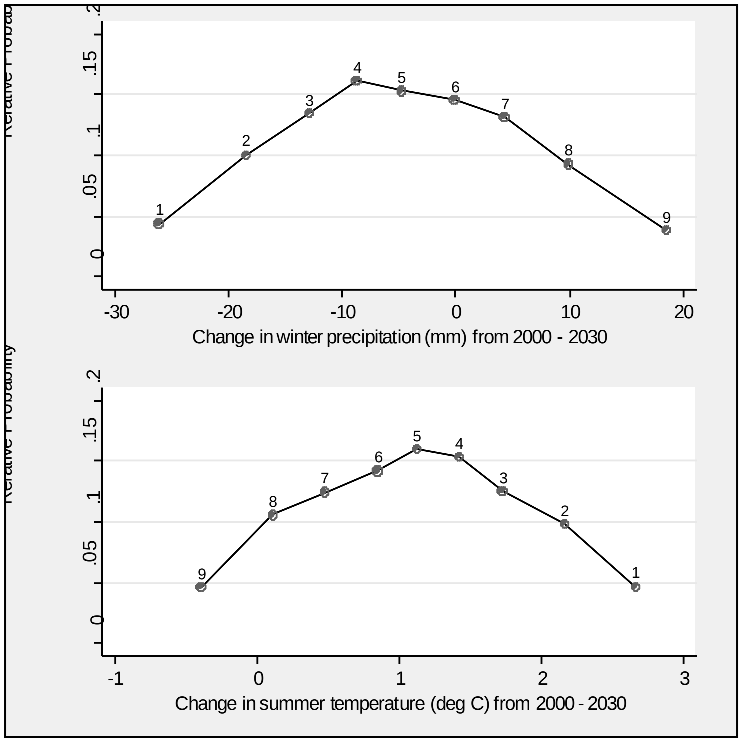

Figure 5: Relative weights applied to numbered weather sequences for winter precipitation (top) and summer temperature (bottom). Lower-numbered sequences correspond to warmer and drier climate.

We then evaluated each of the 90 weather sequences nine different times – one for each possible combination of missing, meeting, and achieving the recycling and replenishment goals. **Table 6** shows the relative weights that we calculated for each based on the survey information collected in the first workshop (as summarized in **Error! Reference source not found.**).

Table 6: Relative probability of missing, meeting, or exceeding the 2005 UWMP recycling and replenishment goals.

	Relative probability	
	Recycling	Chino Basin Replenishment
Miss Goals	56%	50%
Meet Goals	31%	31%
Exceed Goals	13%	19%

Our analysis then weighted these 810 simulation results according to the joint probability of occurring. The weights were calculated by multiplying the individual weights for the temperature and precipitation sequences and the level of achievement for recycling and replenishment, and then dividing by the sum of the weights for all possible combinations. We evaluated each of the four water management plans against the 810 probability-weighted scenarios.

Table 7 summarizes the results of the WMM for the 810 probability-weighted scenarios. 3 The first column reports the probability of any shortage occurring, and the second column reports the probability-weighted average surplus for each of the 810 simulations. According to the performance thresholds established for the standard scenario results above, all four plans perform sufficiently well. One logical interpretation of this presentation of results is that each of the four plans is projected to perform well – they all have low probabilities of shortage and lead to probability-weighted average surpluses of between 20 and 40 taf. Because these results are weighted by the probabilities used to weight the scenarios, however, they could mask important outcomes that are worthy of better understanding, despite their projected low-probability of occurring.

Table 7: Percent of years with shortages.

Cells with shortages less than 10% and with surpluses between 20 and 40 taf are shaded green.

Management Strategy	**Outcome Metric**	
	Probability of shortage	**Average surplus (2006 – 2030)**
Plan A (2005 UWMP)	**7.0%**	**29 taf**
Plan B (+ efficiency)	**3.8%**	**38 taf**
Plan C (+ recycled replenishment)	**5.5%**	**31 taf**
Plan D (+ efficiency & replenishment	**3.2%**	**40 taf**

Shortage exceedance plots of these results provide more information about the range of possible outcomes. **Figure 6** shows that although shortages are projected to occur in only 7% of the years under Plan A (as seen **Table 7**, as well) the shortages can be quite large if they were to occur. For example, according to the probabilities used in this assessment, there is a 1% chance of a 50 taf shortage, and the largest evaluated shortage is about 170 taf (this result occurs in one single year out of one of the 810 simulations – a 0.005% chance).

This figure concurs with **Table 7** and shows fewer shortages for the other plans over Plan A. Plan B, for example, which includes additional efficiency, shows significant reductions in the magnitude of shortages. The 1% shortage level for Plan B is only about 30 taf.

Although these results provide additional information over the simple ranking and summary information presented in **Table 7**, proper interpretation is important. For example, this analysis assumes that the performance of the IEUA water management system in any given year is independent of all other years. In fact, many of the shortages occur in multiple years of the same simulations. So, the IEUA region is more likely to face either no years with shortages at all

[3] Due to time limitations between the first two workshops, we initially developed the probabilistic estimation based on only three levels of goals achievement (assuming that IEUA would miss, meet, or exceed the recycling and replenishment goals together). We have reevaluated this estimate using all nine possible combinations of goals achievement. As a result, **Table 7** and **Figure 6** are different than those shown in Workshop 2.

or many years with shortages. A natural question, then is, which future conditions would lead to numerous shortages.

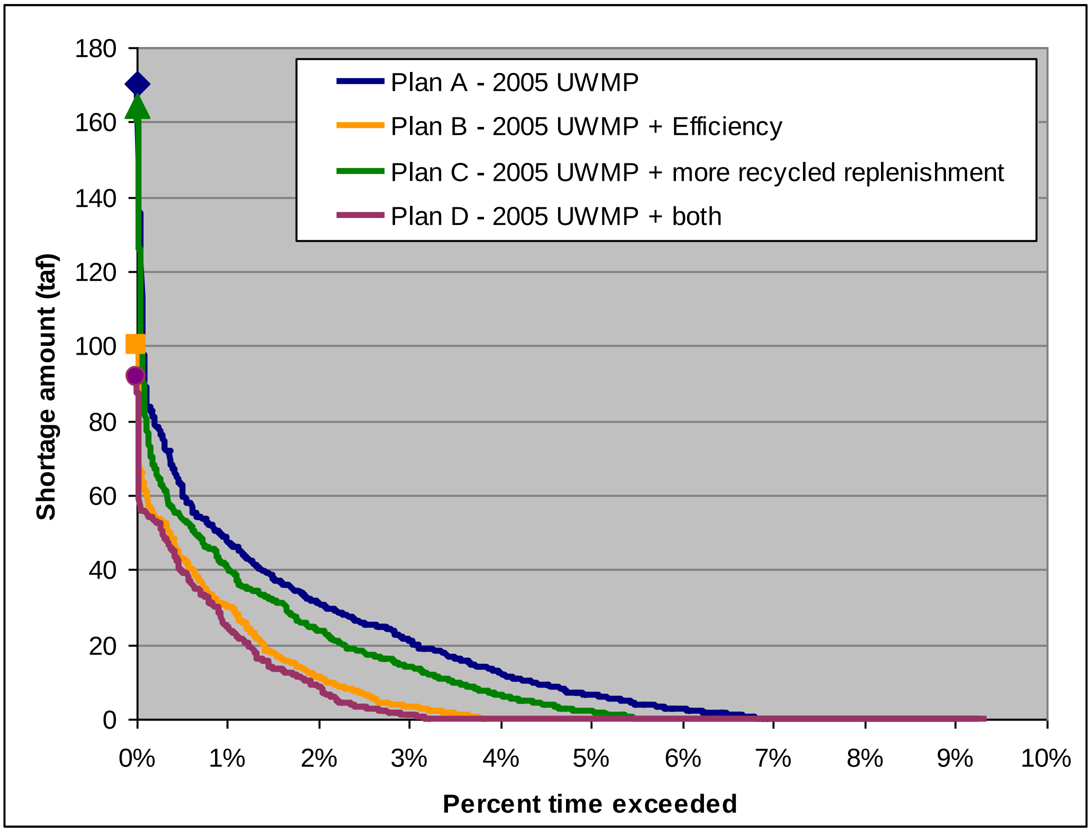

Figure 6: Shortage exceedance plots for the four water management plans based on 810 probabilistically-weighted simulations.

Policy-relevant Scenarios

The last methodology used to assess the impact of uncertainty of IEUA water management was robust decision making (RDM). Using RDM, we evaluated the WMM over a wide range of plausible future conditions and identified a few key scenarios that were most relevant to the choice among plans. An important distinction between RDM and the probabilistic method described above is that the analysis of the results did not require a detailed assessment of the probabilities of various future conditions at the onset of the analysis. This can be an attractive feature when addressing uncertainties that are not well understood (for example, impact of climate change on region weather patterns).

Our RDM analysis began by generating a large ensemble of WMM simulations. Because we were not constrained by availability of probabilistic information we chose a larger set of seemingly-important uncertain parameters to evaluate. Similarly to the probabilistic assessment described above, we evaluate 90 weather sequences reflecting the NCAR-estimated climate trends over the IEUA region. We also evaluated the nine combinations of achievement levels of recycling and replenishment goals, used for the probabilistic assessment.

We also considered three important concerns that IEUA had about future management conditions – (1) level of natural improvement in household water use efficiency, (2) reduction in the permeability of the Chino Basin due to continued urbanization and/or increases in the intensity of precipitation events, and (3) the effect that climate change would have upon imports from the State Water Project (Martha Davis, personal communication).
To evaluate the first, we varied the rate in which water use intensity decreased for new housing from 5% to 20% (equivalent to increasing naturally occurring conservation the same rate). To evaluate the second, we adjusted the projected increase in impermeable surfaces in the Chino basin by up to 20%. Finally, for the last, we varied how much MWD deliveries would be reduced under the different deciles of climate change. We considered the four plausible response relationships of MWD imports to climate change decile shown in **Figure 7**. We sampled quasi-uniformly over the six key uncertain parameters to generate a 900-element ensemble of simulations.

Table 8 summarizes the WMM parameters used and ranges or values used in the experimental design.

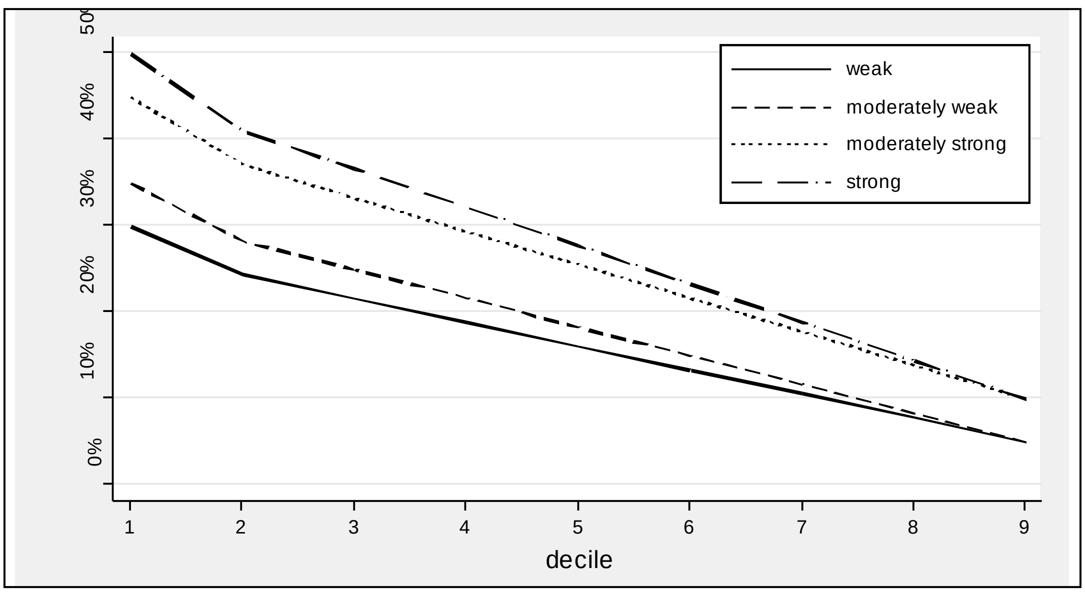

Figure 7: Four responses of imports to climate change decile.

Table 8: Uncertain parameters and value ranges used to generate ensemble of simulations for policy-relevant scenario analysis.

Uncertain Parameter	Description	Values or Range Used
Future weather sequence	Sample from set of 90 discrete weather sequences	1 … 90
Recycling demand	Achievement of recycling goals	Miss, meet, exceed (see **Error! Reference source not found.**)
Replenishment demand	Achievement of replenishment goals	Miss, meet, exceed (see **Error! Reference**

		source not found.)
Naturally occurring conservation for new houses	Trend in water use for new households (over 25-year simulation)	-5% … -20%
Change in percentage of urban areas that is impervious	Decrease in percolation of precipitation in Chino Basin	0% … -20%
Reduction in MWD imports by climate change decile	Impact of climate change on imports	Weak; moderately weak, moderately strong; strong (see Figure 7)

A key objective of RDM analysis is to evaluate a broad range of possible outcomes and improve our understanding of the conditions that lead to unfavorable outcomes. Using the average surplus from 2021 – 2030 as the metric of performance, **Figure 8** shows a frequency histogram of the performance of Plan A (2005 UWMP) for the entire simulation ensemble. The histogram is colored to highlight those simulations in which the average surplus is too low (dark bars – 344 simulations), too high (light bars – 188 simulations), or just right (white bars – 368).

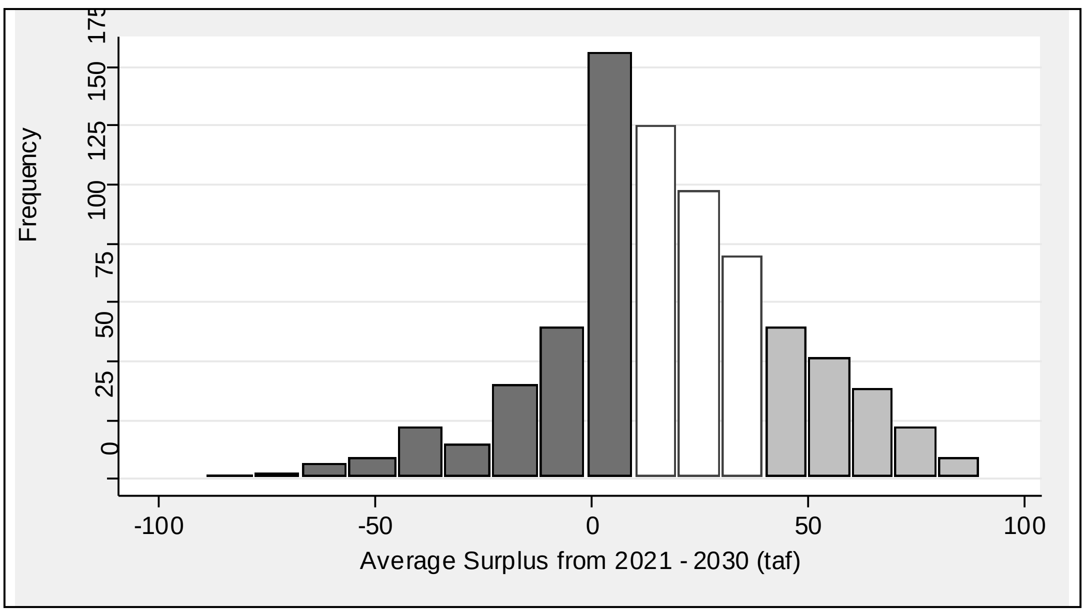

Figure 8: Frequency histogram of average surplus (from 2021 – 2030) for Plan A (the 2005 UWMP).

The bars are colored according to performance – dark bars represent cases in which average surplus is low (less than 10 taf), light bars indicate simulations in which average surplus is high (greater than 40 taf), and white bars indicate simulations with a more desired range (between 10 and 40 taf).

Following the procedure outlined in Groves and Lempert (2007) and Lempert et al. (2006), we use a cluster-finding algorithm called Patient Rule Induction Method (PRIM) (Friedman and Fisher 1999) to find and characterize clusters in the database of simulations that represent management conditions in which the 2005 UWMP performs poorly. PRIM is a data-mining algorithm designed to generate a set of low-dimensional "boxes" in high-dimensional data containing regions where the value of a particular function is large (or small) compared to its value outside these boxes. PRIM seems particularly useful for suggesting scenarios because it aims to optimize both the classification accuracy of the boxes (the percentage of large or small function values they contain) and the interpretability of the boxes (the simplicity of the rules needed to define them).4

The PRIM algorithm suggests two clusters of simulations that have low performance. The first cluster, which captures 203 of 344 low surplus simulations, is characterized by conditions in which the recycling goals are not exceeded, weather sequences are consistent with the drier deciles (1-4), and percolation to the Chino Basin decreases (as proxied by increases between 2.5% and 20% in impermeable surfaces in the urban areas) (**Figure 9**). We suggest that these ranges of input values characterize an important "scenario" because Plan A (2005 UWMP) consistently performs poorly under these conditions as seen in **Figure 10**. We call it the Dry, Flashy, and Low Recycling scenario, as it reflects conditions in which climate change reduces annual precipitation in the region, infiltration to the Chino Basin is low (due in part to more "flashy" storms), and recycling levels are lower than anticipated.

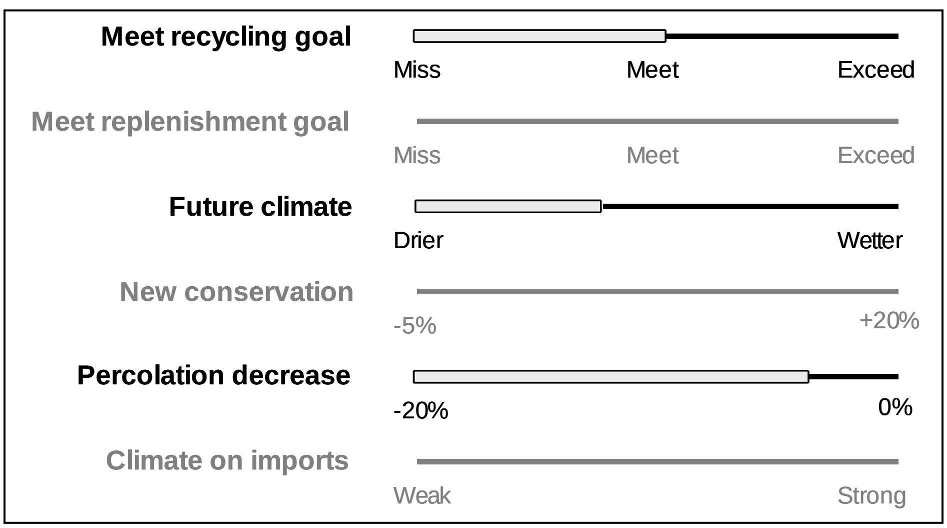

Figure 9: Parameter ranges specifying the Dry, Flashy, and Low Recycling scenario.

[4] We implement PRIM using publicly available software that inputs a dataset (which can be the output of a model run over many combinations of input values) and a criterion for cases of interest. The algorithm outputs descriptions of several alternative low-dimensional regions, or "boxes," that contain a high density of and span a high proportion of the interesting cases.

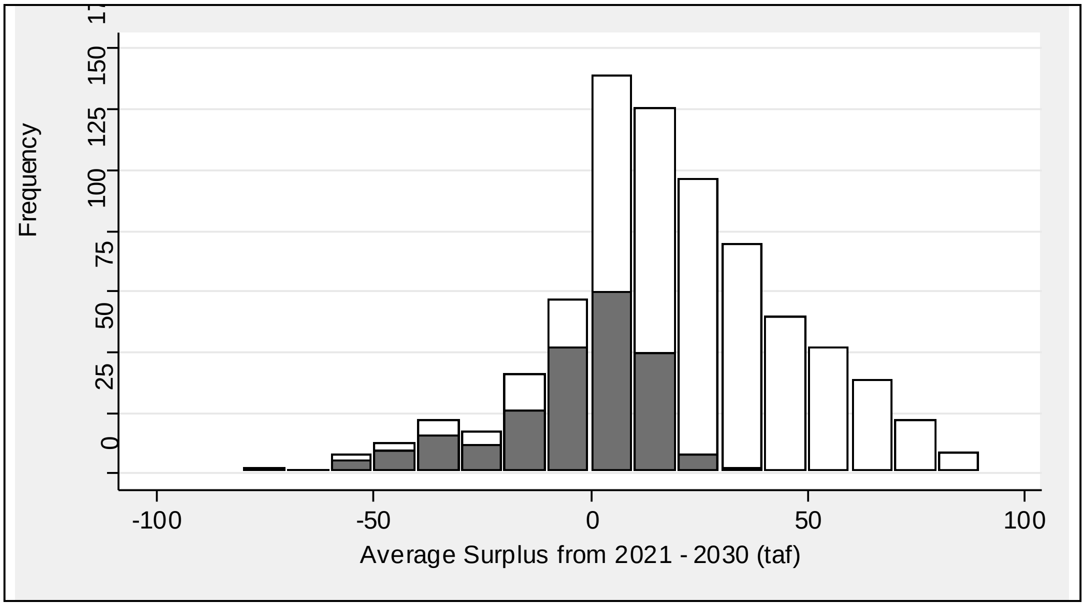

Figure 10: Frequency histogram of average surplus (from 2021 – 2030) for Plan A (the 2005 UWMP) under all modeled conditions (white bars) and those consistent with the Dry, Flashy, and Low Recycling scenario (dark bars).

The PRIM algorithm also identifies another cluster of input parameter values that lead to poor performance of Plan A. This second cluster is defined as cases in which the recycling goals are exceeded and weather sequences are consistent with the higher deciles (8 or 9) (**Figure 11**). We call this scenario the Wet, Effective Recycling scenario, and it captures 131 of the 188 high surplus cases. This scenario leads the 2005 UWMP to consistently produce excess supplies, despite the achievement of replenishment goals, the levels of new conservation, percolation decreases, or the strength of climate change on imports.

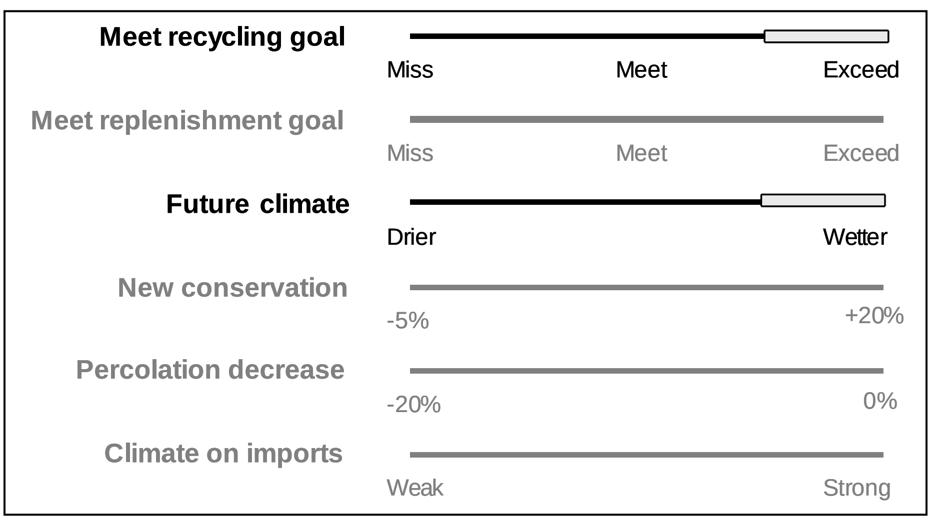

Figure 11: Parameter ranges specifying the Wet, Effective Recycling scenario.

We now have identified two important scenarios that characterize 63% of all the bad outcomes. All other simulations that are not members of these two scenarios can be considered a member of a third scenario which we call “Favorable Conditions”. We now evaluate the performance of all four plans under these three scenarios in terms of the average surplus from 2021-2030 (**Table 9**). Plan A, as expected performs well under the Favorable Conditions scenario (27 taf) and poorly for the other two (-0.3 taf for the Dry, Flashy, Low-Recycling scenario and 53 taf for the Wet, Effective Recycling scenario). Plans B and D (which include more aggressive efficiency) show significant improvements under the Dry, Flashy, Low-Recycling scenario, but exacerbate poor performance under the Wet and Effective Recycling scenario – the added efficiency leads to even greater surpluses.

Table 9: Average surplus (2021-2030) for four management plans under the three policy-relevant scenarios. Cells with surpluses between 20 and 40 taf are shaded green, between 10 and 20 taf and between 40 and 60 taf are shaded yellow, and less than 10 taf and greater than 60 taf are shaded red.

Management Strategy	Scenario		
	Favorable Conditions	Dry, Flashy, Low-Recycling	Wet and Effective Recycling
Plan A (2005 UWMP)	27 taf	-0.3 taf	53 taf
Plan B (+ efficiency)	42 taf	16 taf	68 taf
Plan C (+ recycled replenishment)	29 taf	5 taf	55 taf
Plan D (+ efficiency & replenishment	46 taf	20 taf	72 taf

These results suggest that no single plan evaluated is robust – that is, neither of them perform adequately well across all three scenarios. Although this appears to be a similar finding to that for the standard scenarios, there is a key difference. Because the three scenarios were developed in response to the performance of a specific plan (the 2005 UWMP in this case), we know exactly how well the scenarios characterize the risk of poor performance. In this case, we know that the two scenarios account for 334 of the 532 poor outcomes. Note that standard scenario analysis above provided no such information about the quality of the scenarios generated. The higher the percentage of bad cases covered by the scenarios, the more confident one can be that the critical risks to the management plans are characterized. The better the risks are clarified, the more useful the scenarios are for informing the tradeoffs of various policies.

These policy-relevant scenarios suggest two alternative analytic paths. One could use the information about the plans vulnerabilities to improve the plans. For example, efficiency appears to improve the performance of Plan A under the Dry, Low-Recycling scenario, but leads to over supply when conditions are otherwise. An improved strategy may increase efficiency but reduce investments in recycling and other supply enhancing projects if climate change effects appear to be more benign (more on the wet end of the range of effects – higher decile). In ongoing work, we evaluate adaptive policies that may be more robust to the critical uncertainties.

An alternative is to consider just the four original Plans but choose among them using the information provided by the RDM analysis. To demonstrate this simplistically, we consider only the tradeoff among policies under the Favorable Conditions scenario and the Dry, Flashy, Low Recycling scenario. Looking at **Table 9**, it is clear that if one were 100% certain that the Favorable Conditions scenario were likely to come to pass, then Plans A or C would perform the best. Alternatively, if one were 100% that the future would resemble the conditions characterized by the Dry, Flashy, Low-recycling scenario then Plan D would be the most prudent.

Using the data from the RDM simulations, we calculate the likelihood of the Dry, Flashy, Low-recycling scenario that would lead a risk-neutral decisionmaker to be indifferent between Plan A and Plan D. That is, we calculate what weight we would have to put on the Dry, Flashy, Low-recycling scenario cases to lead to average surpluses to be equivalent for Plan A and Plan D. This "tipping point" is calculated to be about 25%. **Figure 12** shows a representation of this information.

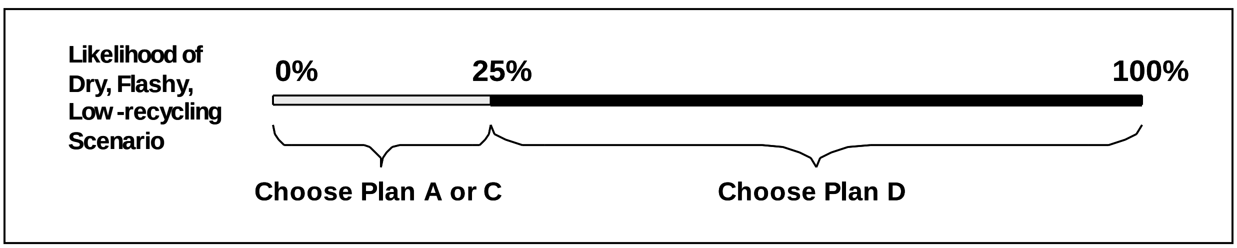

Figure 12: Representation of optimal Plan choices under different subjective assessments of the likelihoods of future conditions being consistent with the Dry, Flashy, Low-recycling scenario.

This information may be quite useful to the IEUA. They could now consider more carefully how likely they think the scenarios are. For example, they could accept the probabilistic climate change information provided by NCAR, use the subjective assessments of the achievement levels for recycling and replenishment, and seek additional information to calculate what the probability of the Dry, Flashy, Low-recycling, scenario is. As an example of this, we used the NCAR information, the subjective assessments of recycling and replenishment, and assumed uniform distributions for the other uncertain parameters to estimate the probability of the Dry, Flashy, Low-recycling, scenario. Our calculations suggest that it is 27% likely – slightly to the right of the "tipping point" in **Figure 12**.